Combination of searches for anomalous top quark couplings

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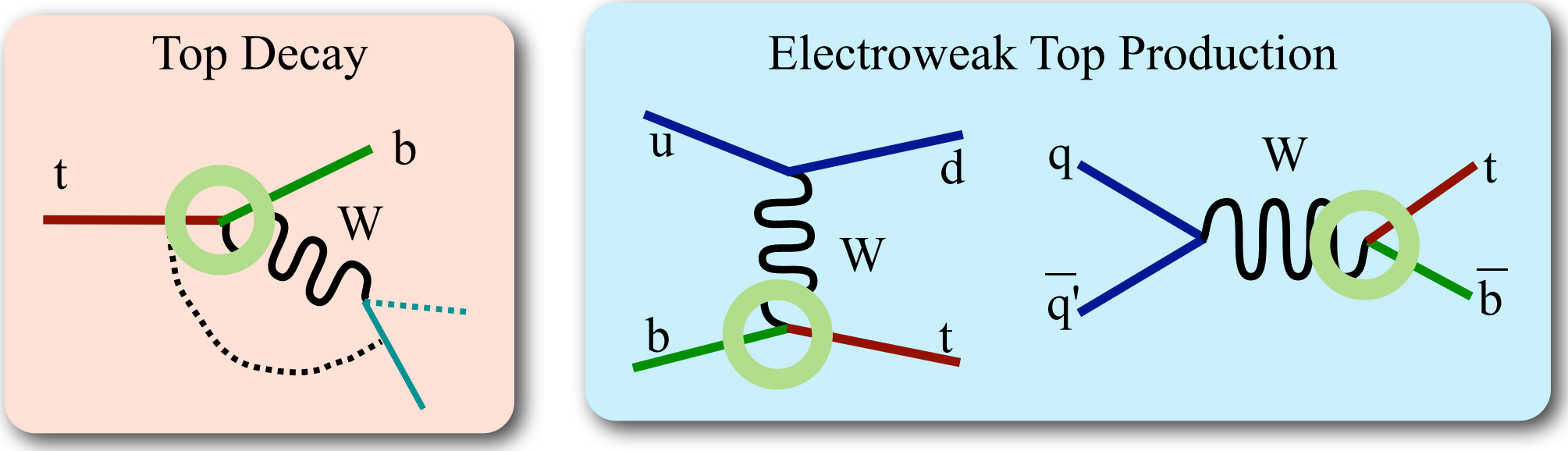
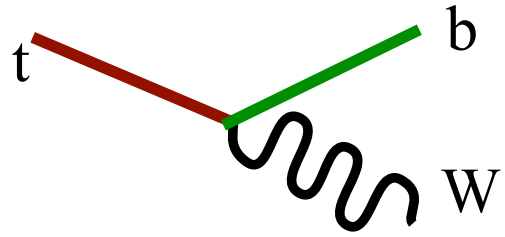
Wtb coupling in top quark events



- Top quark final states are sensitive to nature of the top quark couplings:
  - W boson helicity in top quark decay
    - Angular correlation
  - Single top production
    - Production cross section
    - Angular correlations of final state products

Coupling form factors

- Electroweak Lagrangian has left-handed and right-handed, vector and tensor couplings



$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}(f_V^L P_L + f_V^R P_R)tW_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}V_{tb}}{M_W}(f_T^L P_L + f_T^R P_R)tW_{\mu}^{-} + h.c.$$

- In the SM, $f_V^L = 1$, $f_V^R = f_T^L = f_T^R = 0$

Anomalous couplings

- General Analysis of Single Top Production and W Helicity in Top Decay
  - Ren, Larios, and Yuan (PLB 631, 126, 2005)
- Specifies relationship between Wtb couplings
  - and W helicity – sensitive to ratios of couplings
  - and single top production – sensitive to magnitude of couplings
- Alternative parameterization in terms of dimension-6 operators:
  - Zhang & Willenbrock (PRD 83, 034006, 2011)
  - Aguilar-Saavedra (NP B812, 181, 2009)

$$f_V^L = 1 + C_{\phi q}^{(3,33)*} \frac{v^2}{V_{tb}\Lambda^2} ,$$

$$f_V^R = \frac{1}{2} C_{\phi\phi}^{33} \frac{v^2}{V_{tb}\Lambda^2} ,$$

$$f_T^L = -\sqrt{2} C_{dW}^{33*} \frac{v^2}{V_{tb}\Lambda^2} ,$$

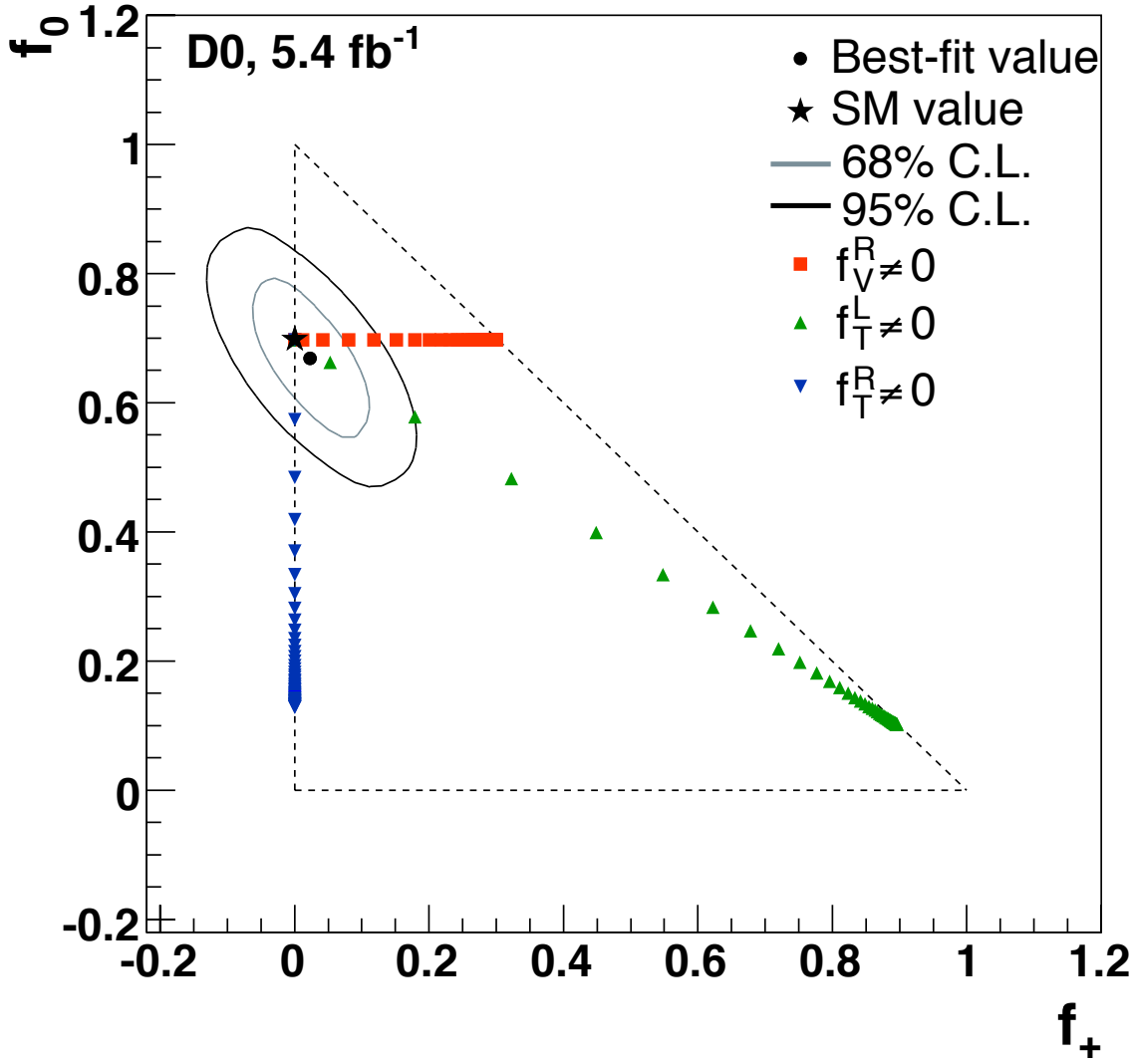
$$f_T^R = -\sqrt{2} C_{uW}^{33} \frac{v^2}{V_{tb}\Lambda^2} ,$$

Combined analysis

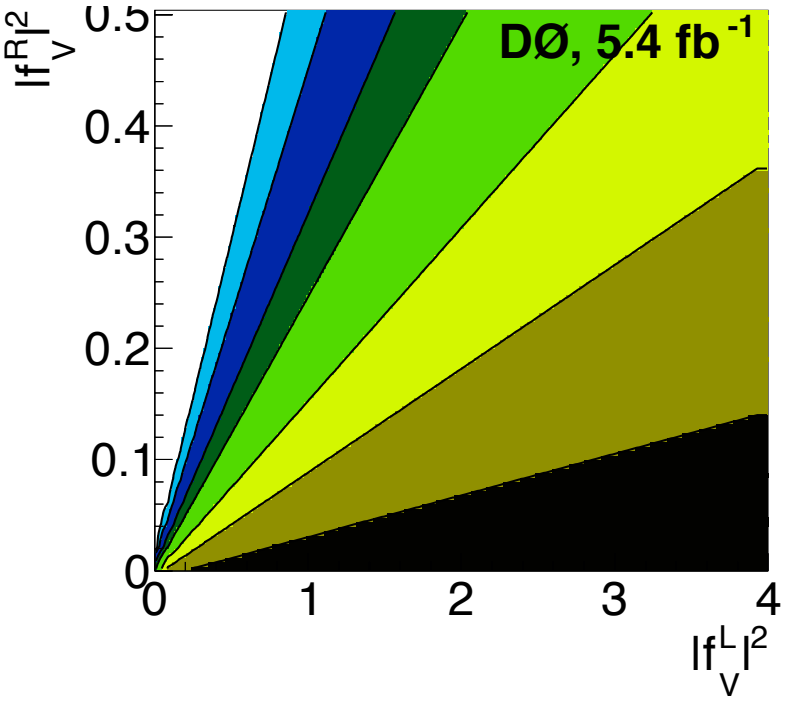
- Update to previous combination based on 0.9 fb^{-1} for single top and 2.7 fb^{-1} for W helicity
- W helicity (Erich):
  - Same cuts, channels, events as PRD analysis (5.4 fb^{-1}) PRD 83, 032009, 2011
  - Lepton+jets and di-lepton channels
- Single top anomalous couplings (Jyoti):
  - Same MVA as anomalous coupling PLB (5.4 fb^{-1}) PLB 708, 21, 2012
- Top mass of 172.5 GeV
- Combination (Reinhard):
  - Bayesian analysis, output of W helicity analysis forms input prior to single top anomalous couplings
  - Include all W helicity systematics and all single top systematics
  - Take all correlations of systematic uncertainties into account.

W helicity analysis

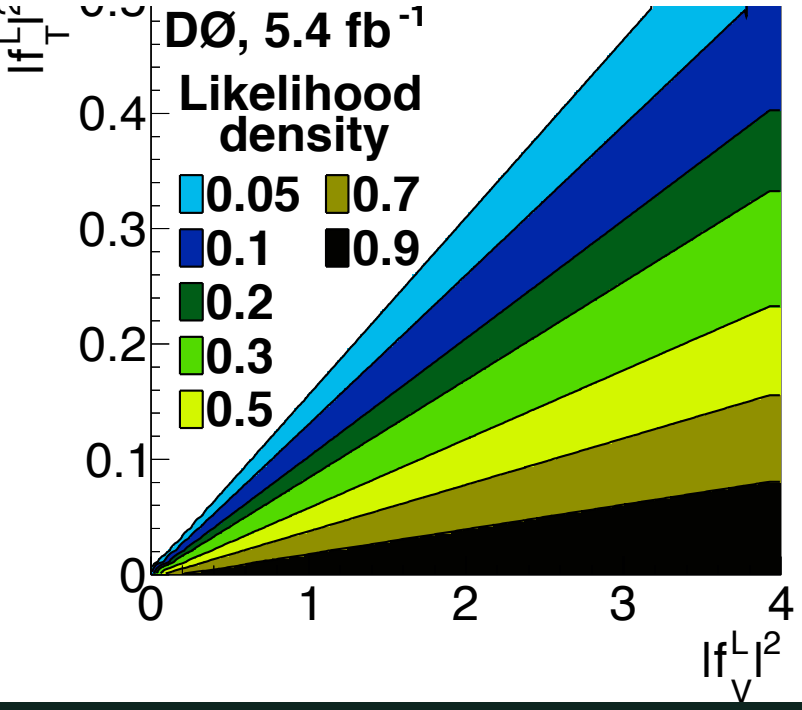
- 5.4 fb^{-1}, top decays to di-lepton and lepton+jets
- PRD 83, 032009, 2011

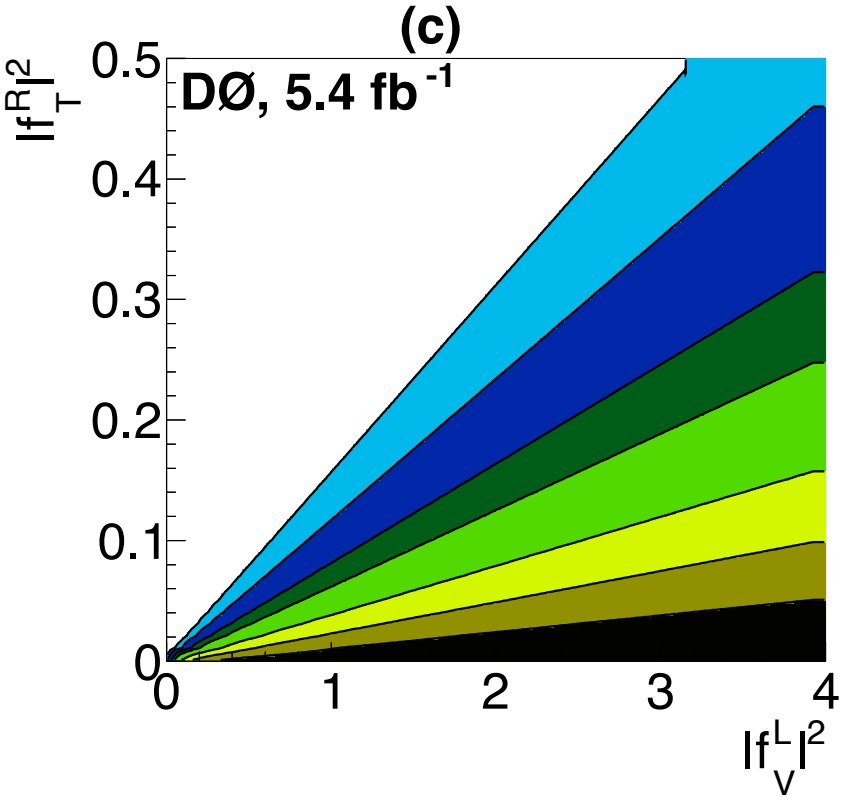


Anomalous couplings in W helicity



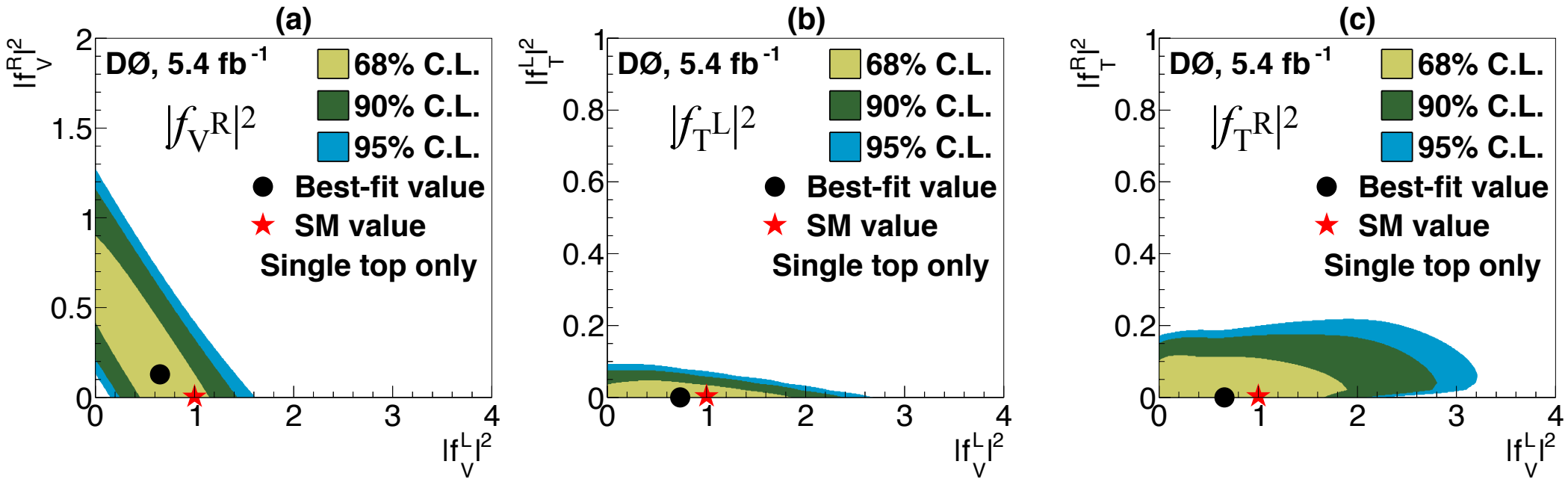
- contours of equal probability density
- Since only ratio is constrained, give probability fraction for each contour
- All systematic uncertainties included





Anomalous couplings in single top

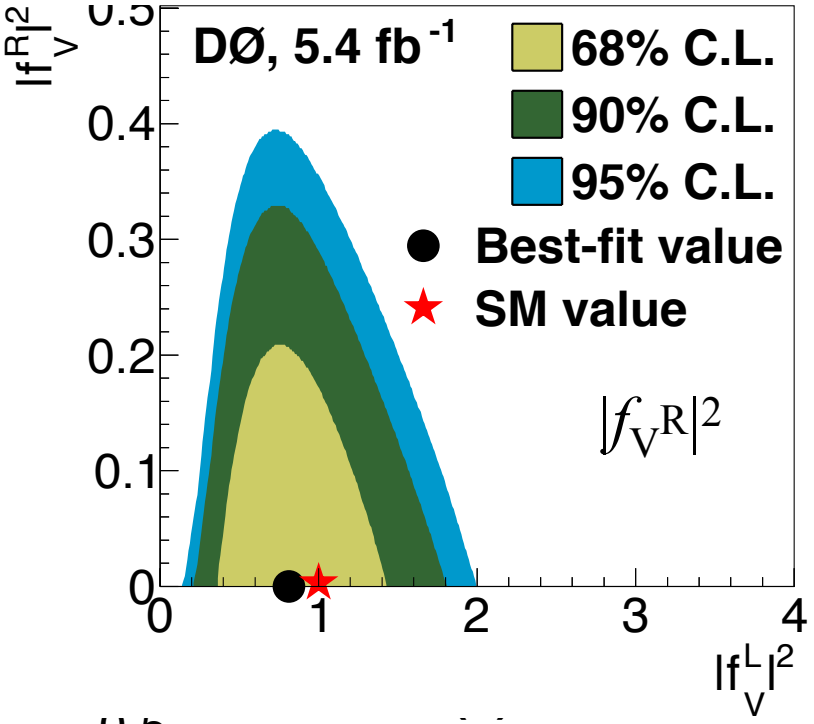
- BNN filter (same as in SM single top analysis)
  - Additional angular variables
  - Trained separately for each anomalous coupling
- 2-jet and 3-jet events
  - Veto 4-jet events to stay orthogonal to W helicity
  - ONly small change from PLB
- Form 2d Bayesian posterior for coupling squared
- Limit on anomalous coupling from integral over SM coupling

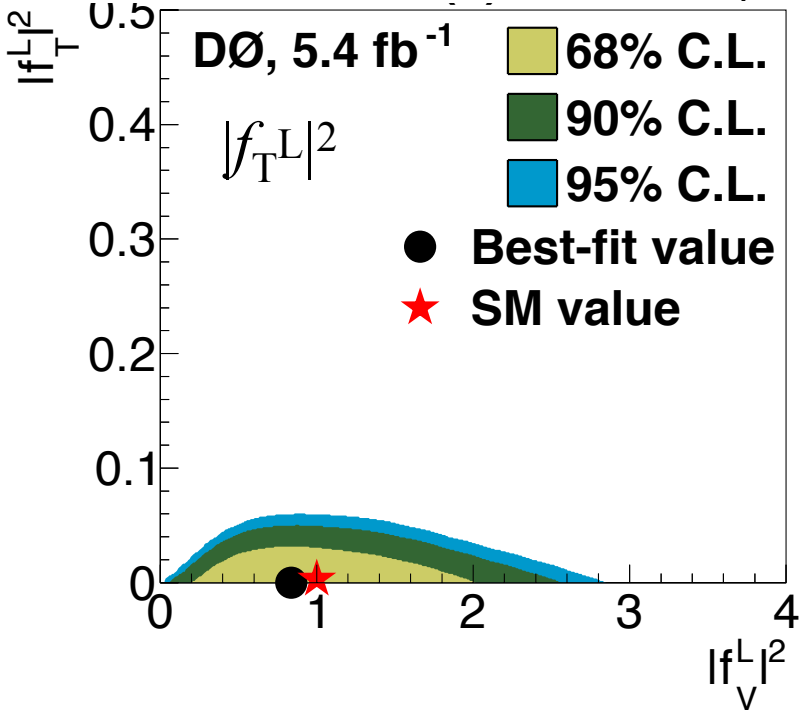


Systematic uncertainties

- 3 categories of systematics
- Those only affecting W helicity analysis
  - Template statistics, ttbar modeling, analysis consistency
  - Include these in the W helicity likelihood output
- Those only affecting single top analysis
  - W and QCD normalization to data, ...
  - Include these in the single top coupling analysis
- Those affecting both
  - Cross sections, PDFs, JES, ...
  - Single top analysis did not have top mass systematic, but that has been added to be consistent with W helicity measurement (it's small)
  - Integrate over Gaussian priors for all systematics
  - For each set of systematic shifts, re-calculate the W helicity likelihood
    - Then use that as an input prior to the single top anomalous coupling analysis

Combined top couplings posteriors





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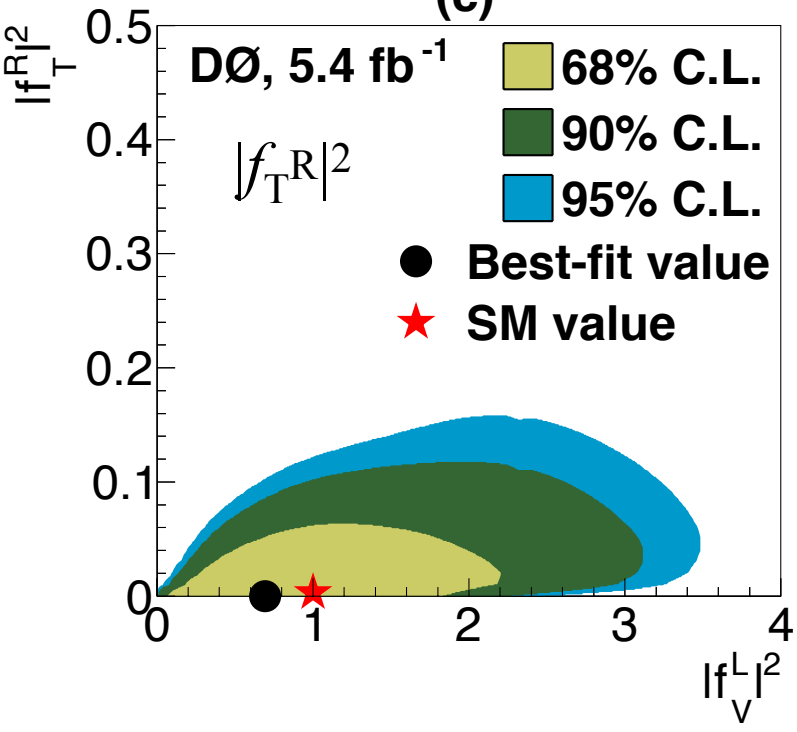

Anomalous coupling limits

- Observe SM-like coupling
- Set 95% CL limits on non-SM couplings:

Scenario	only W helicity	only single top	combination
$\lvert f_V^R\rvert^2$	0.62	0.89	0.30
$\lvert f_T^L\rvert^2$	0.14	0.07	0.05
$\lvert f_T^R\rvert^2$	0.18	0.18	0.12

- Converted to operator language:

$$|C_{\phi q}^{(3,33)}| < 14.7$$
$$|C_{\phi\phi}^{33}| < 18.0$$
$$|C_{dW}^{33}| < 2.5$$
$$|C_{uW}^{33}| < 4.1$$

  - Operator limits worse than preliminary LHC W helicity results, but those use priors flat in coupling

Summary

- Set limits on anomalous Wtb couplings using all applicable top quark information
  - Combining W helicity and single top analyses
  - Updated analysis using latest results
- World's best limits